Image Acquisition - Sensors and Sources

William W. Moses
Lawrence Berkeley National Laboratory
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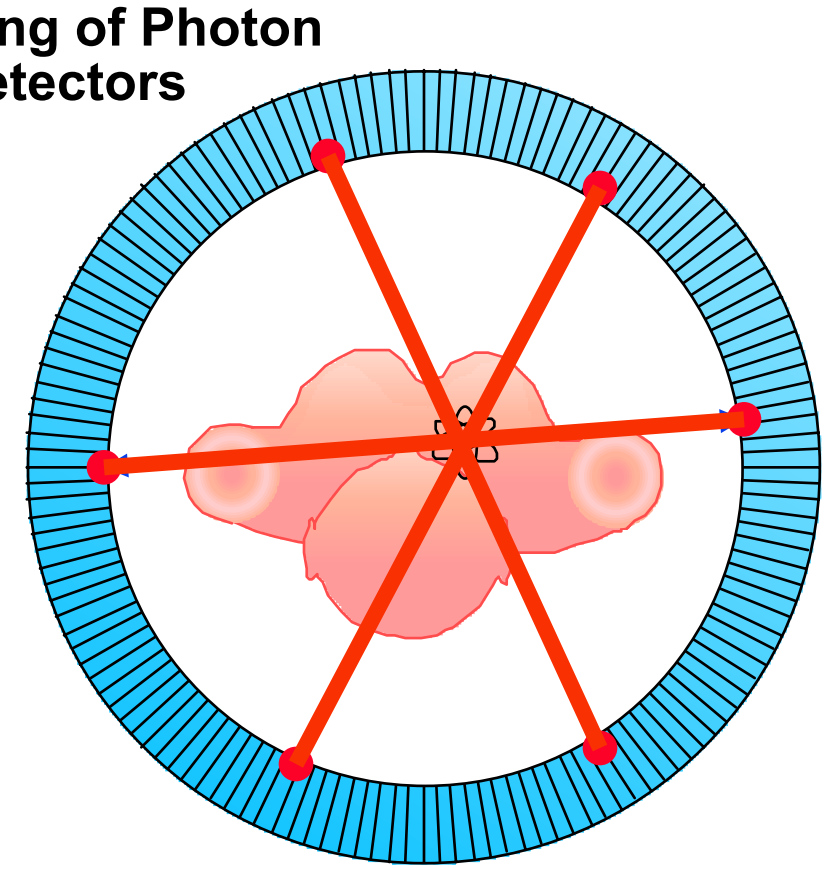
Outline:

- Introduction
- Benefits of Improved Sensors
- Recommendations

Existing Sensors Limit Performance!!!
Example: PET



- Radiotracer decays by emitting a positron (β^+).
- 511 keV photon pairs detected via time coincidence.
- Positron localized to line (defined by detector pair).
- Image reconstructed using computed tomography.

- Perfect Sensor $\Rightarrow$ Time-of-Flight Localizes Positron to Point
- PET becomes PI (Positron Imaging)?

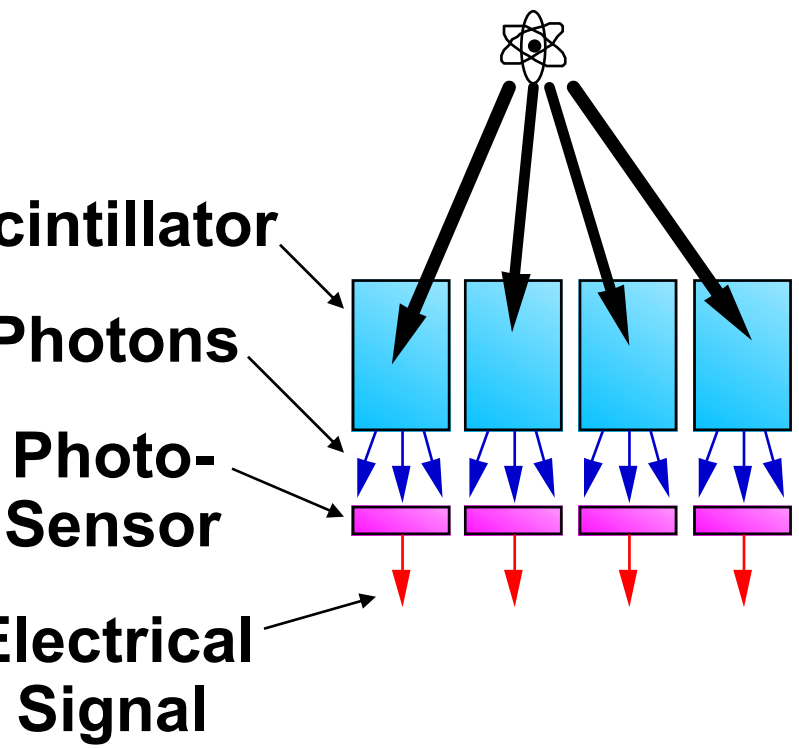
Energy per Quantum

Imaging Modality	Energy / Quantum
PET	5×10^{5} eV
SPECT	1×10^{5} eV
X-Ray	5×10^{4} eV
Optical	2×10^{0} eV
Ultrasound	2×10^{-2} eV
MRI	1×10^{-13} eV

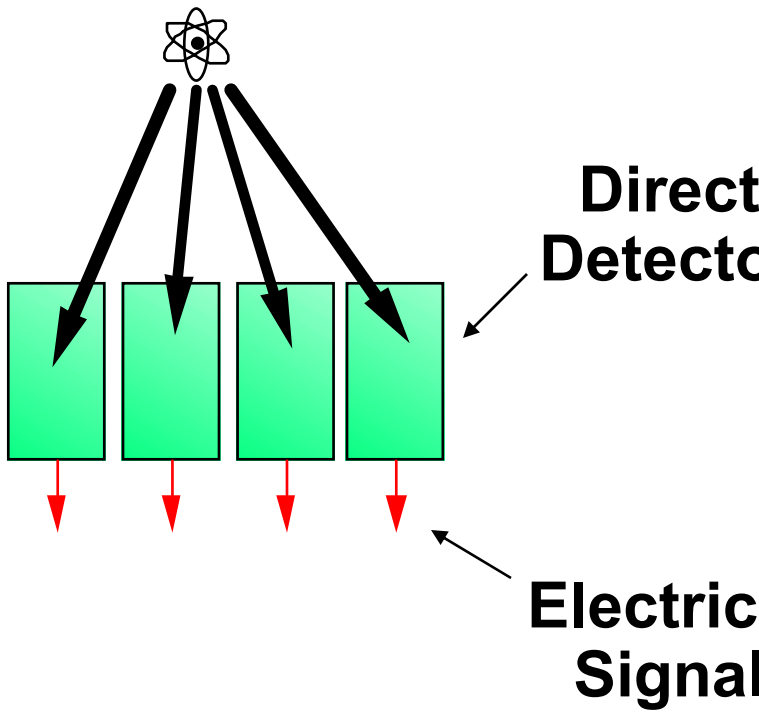
Wide Range of Energies $\Rightarrow$ Wide Range of Senso

Sensors for Medical Imaging

Scintillation Detector

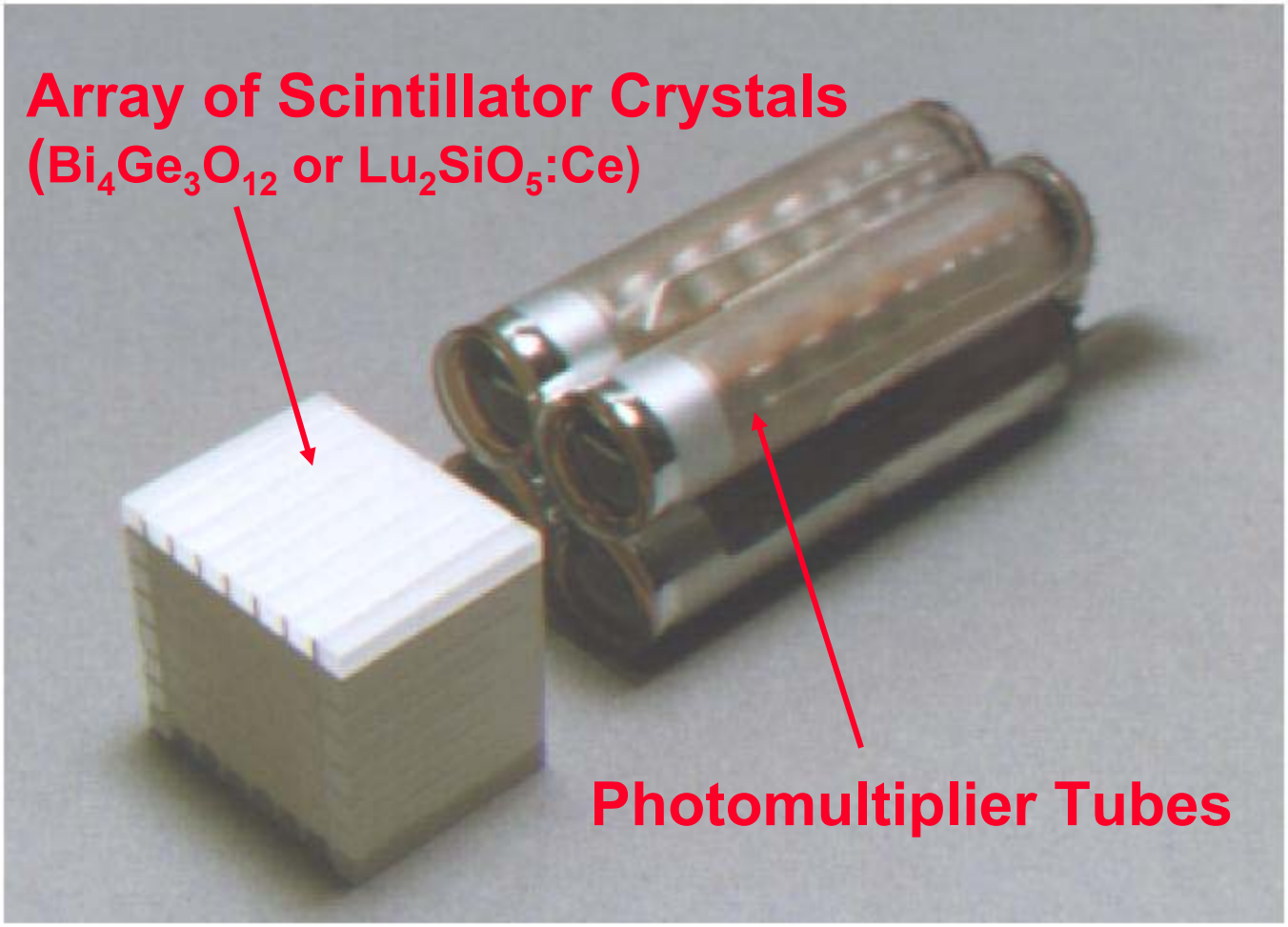


Solid State (or Direct) Detector



Sensors Are Optimized for Each Modality, But General Concepts are Identical

Typical Sensor for PET



PET Needs

Improve Timing Resolution

- Reduce Random Event Background (Up to 50% of Total Events)
- Use Time-of-Flight to Reduce Noise Variance (by 5x-10x)

Improve Energy Resolution

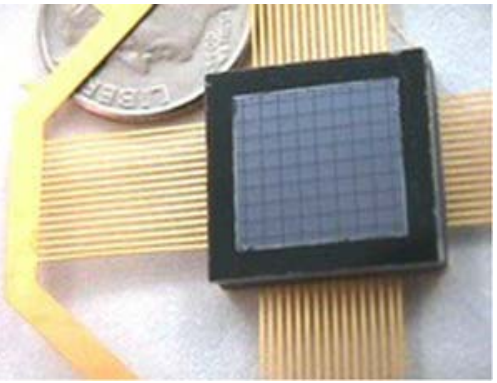
- Scattered Events Often Outnumber True Events

Improve Spatial Resolution

- Isotropic Resolution Throughout the Field of View
- Small Animal Imaging

SNR is Main Limitation in Clinical PET

PET: Potential Sensor Improvements



New Scintillators

- Improved Timing Resolution
- Improved Energy Resolution

Avalanche Photodiodes

- Smaller Pixels improves Spatial Resolution
- Higher Quantum Efficiency (80% vs. 25%), can improve Energy Resolution
- Better Stability

Solid State Detectors Not Useful for PET

- Too Slow (speed of sound vs. speed of light)
- High Cost per Unit Volume

New Sensors Can Improve Spatial Resolution and Significantly Reduce Background

Typical Sensor for SPECT

SPECT: Needs

Improve Energy Resolution

- Reduce Scatter Background
- Over 35% of SPECT Events are Scatter

Improve Stability

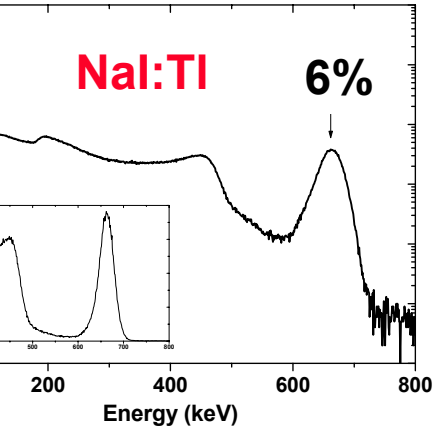
- Maintain Calibration

Improve Resolution / Efficiency Tradeoff

- Set by Collimator
- Major Improvements Difficult

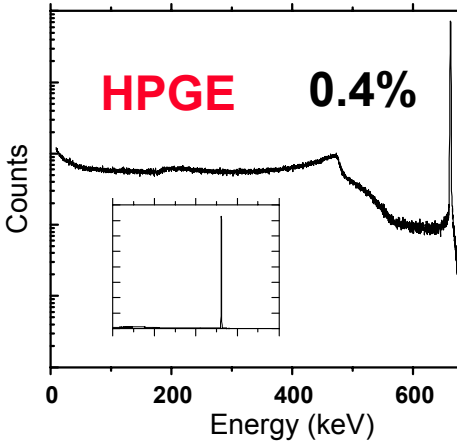
Energy Resolution is Main Limitation in SPECT

SPECT: Potential Sensor Improvements



New Scintillators

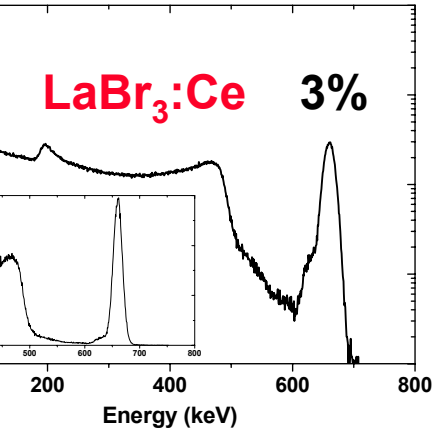
– Improved Energy Resolution

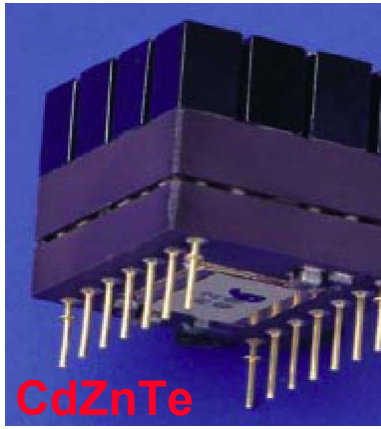


Solid State Detectors

– *Much* Improved Energy Resolution

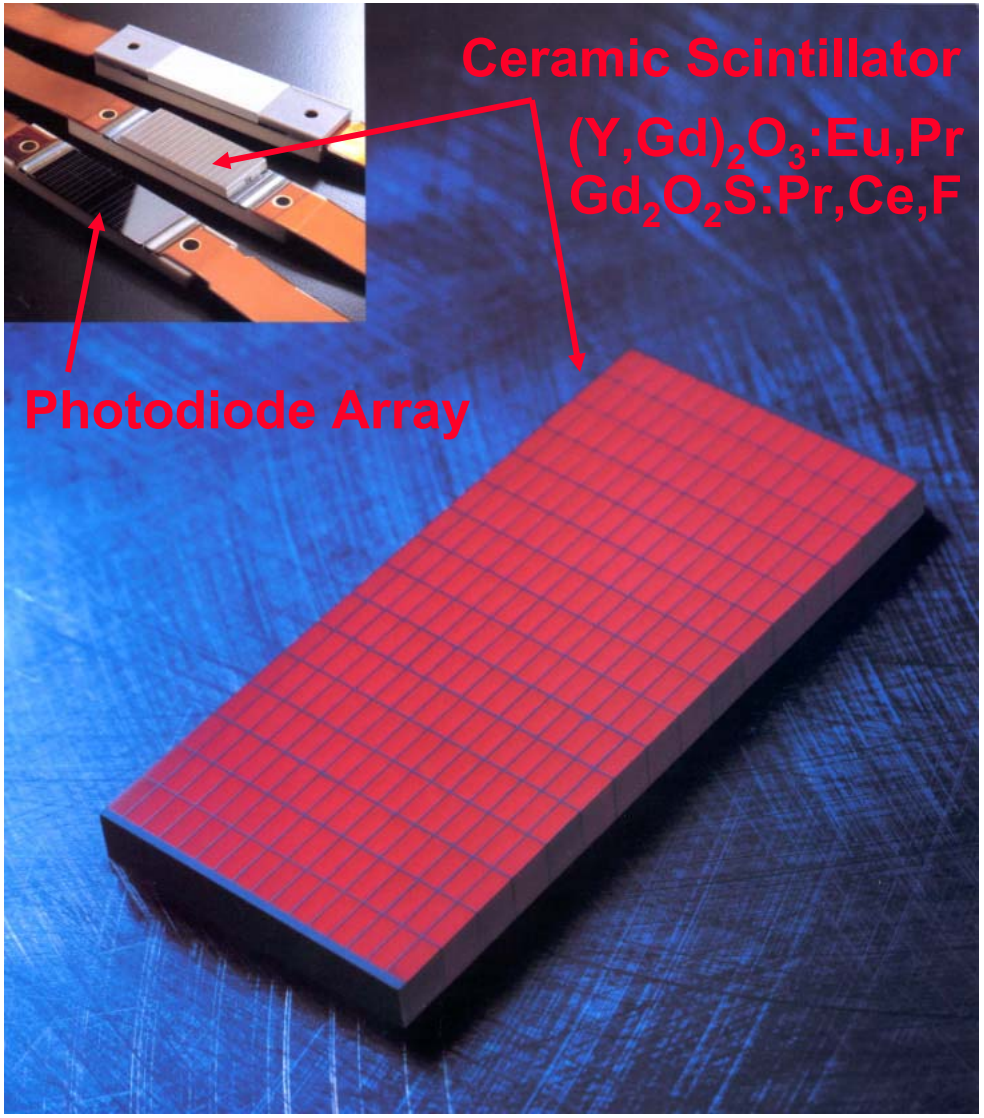
– Improved Stability





est Theoretical Energy Resolution with Solid Sta

Typical Sensor for X-Ray CT



X-Ray CT: Needs

Reduced Dose

Improved Spatial Resolution

- 0.5 mm to 0.2 mm
- Difficult Without Increasing Dose or Increasing Noise

Reduced Imaging Time

- Factor of 2

Scintillator & Photodetector: Little Improvement Possible

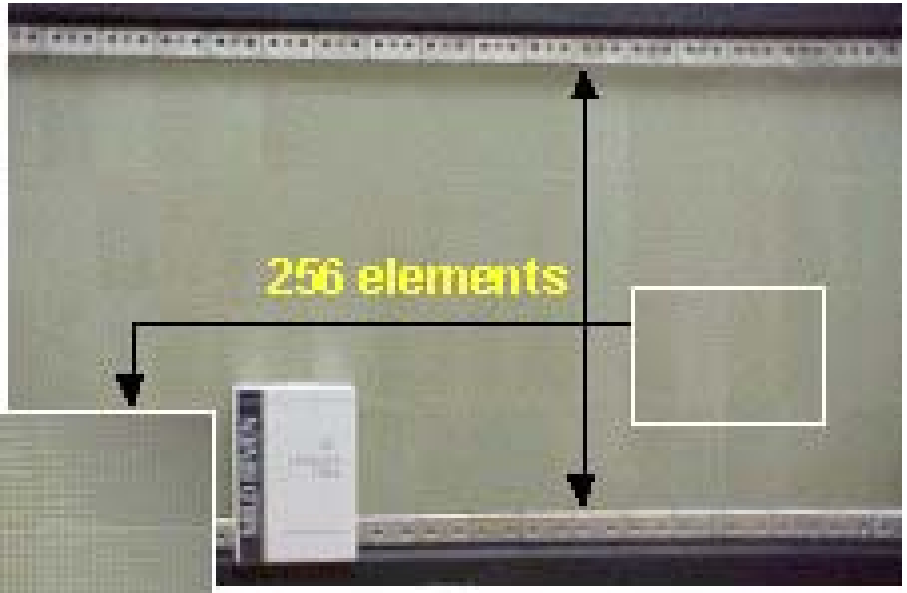
- Scintillator: High Luminous Efficiency & QE, Low Afterglow
- Photodetector: High QE, Very Stable

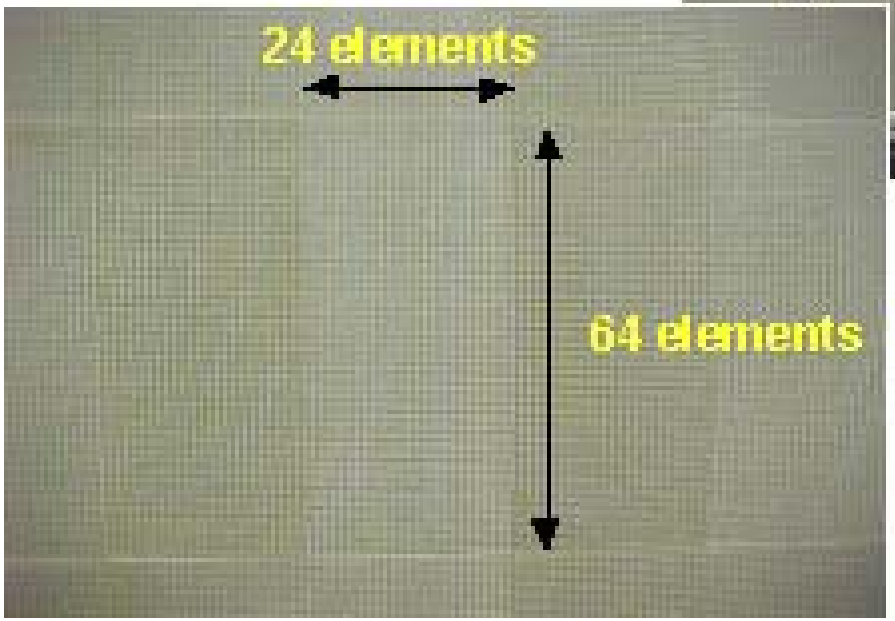
Main Limitation in CT is Dose

X-Ray CT: Potential Sensor Improvements

nsor: Larger 2-D Arrays

- High Channel Density (Thermal Management, Connection Density)
- Maintain Mechanical Tolerances
- Want Thinner Reflector





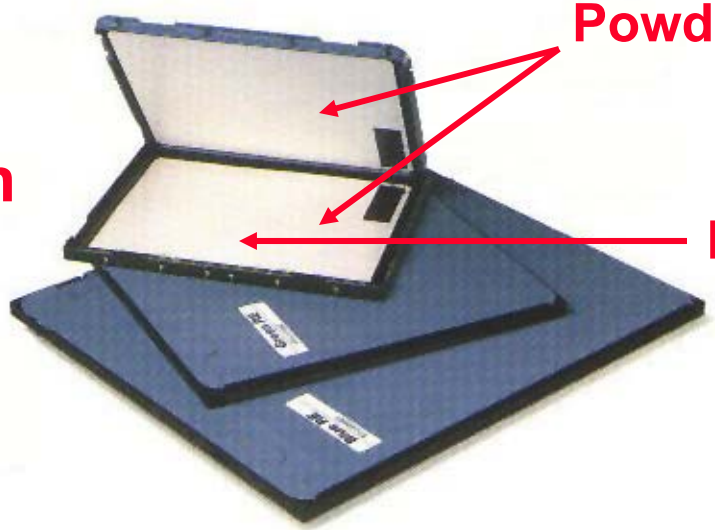
Source: Higher Power

- Same Dose in Shorter Ti
- Monochromatic Source?

Significant Reduction in Acquisition Time

Typical Sensor for Planar X-Ray

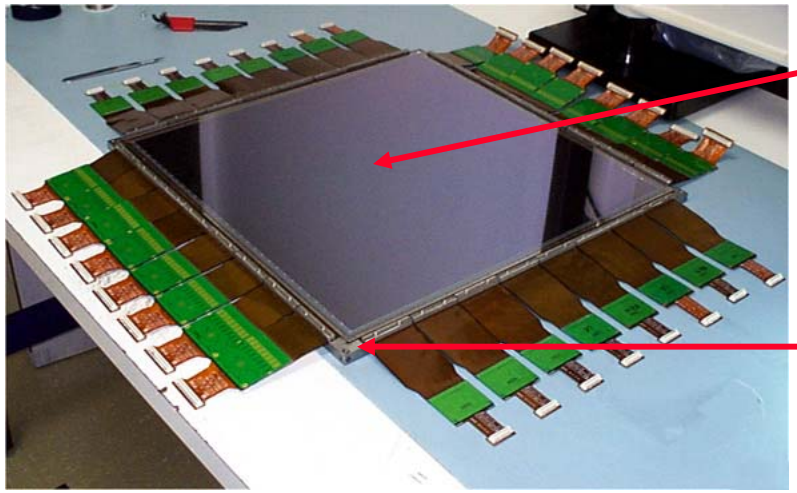
Film / Screen



Powdered Scintillator Screen
(Gd_2O_2S:Tb)

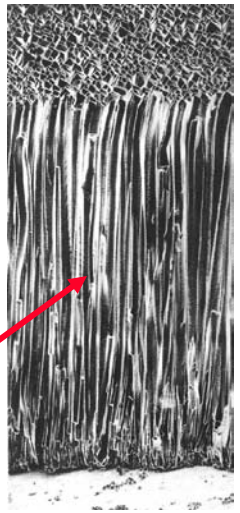
Photographic Film
(not shown)

Digital

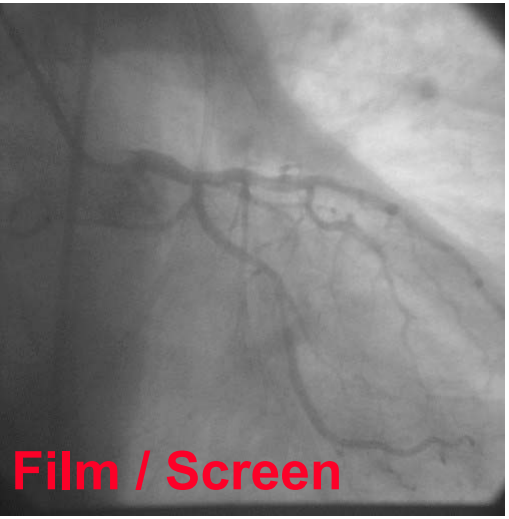


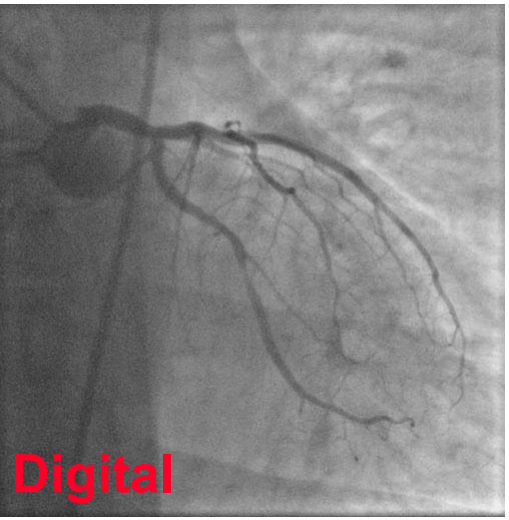
Photodiode Array

Scintillator Screen
(Columnar CsI:Tl)



Planar X-Ray: Needs





Scintillator & Photodetector: Little Improvement Possible

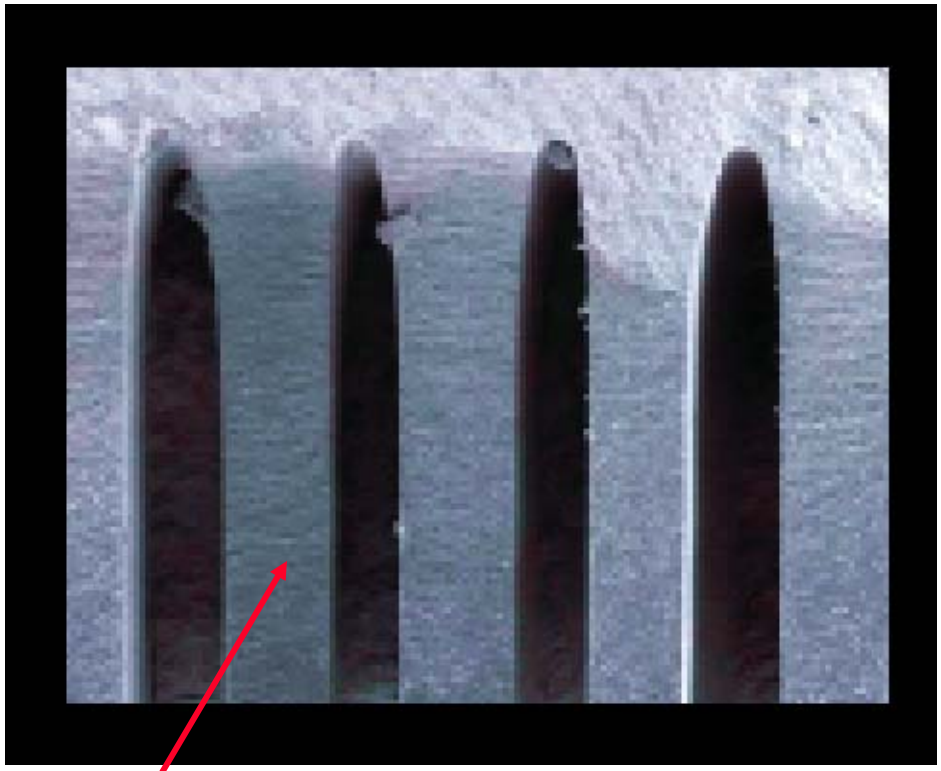
- High Luminous Efficiency
- High Detective Quantum Efficiency (>70%)

Some Improvement Possible:

- More Portable, Durable, Lighter
- Improved Falloff of DQE with Spatial Frequency
- Better Scatter Rejection / Dose Tradeoff?
  - Slot Scan?
  - More Efficient Scatter Grids?

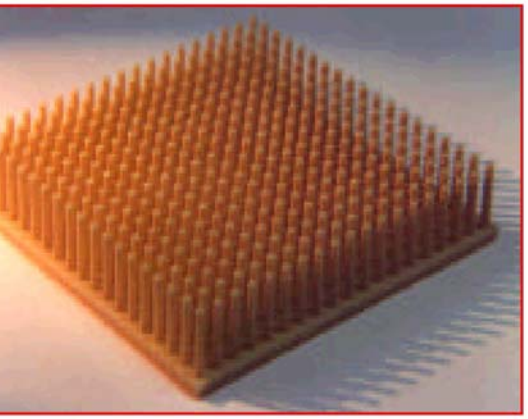
Digital X-Ray Sensors Close to Ideal

Typical Sensor for Ultrasound



Piezoelectric Ceramic

Ultrasound Transducer Needs



Real-Time 3-D Imaging

- 2-D Arrays

Greater Bandwidth

- Same Transducer Used for Many Frequencies

Reduce Reflection at Tissue Interface

- Match Transducer & Tissue Impedance

Higher Frequency

- Higher Resolution $\Rightarrow$ Small Animal Imaging

Room for Improvement in Many Aspects

Recommendation 1: New Materials

Material Discovery

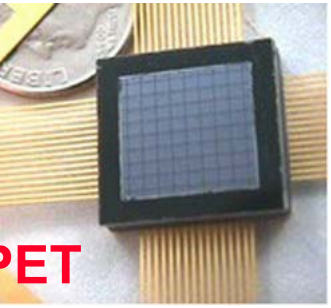
- Scintillators
- Solid State Detectors
- Ultrasound Transducers
- *Very* Little Current Effort

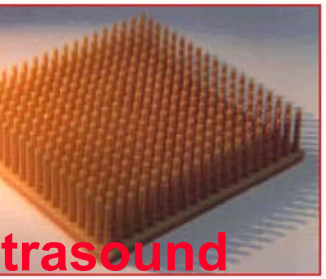
Material Development

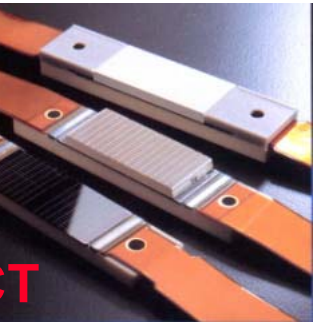
- Difficult & Expensive
  (Minimum 10 years @ $1M / year for each Material)
- Done by Commercial Sector (if Patent Protected)
- Done by Government (if Not Patent Protected)

irtually All Modalities Need New Sensor Material

ecommendation 2: Electronics & Packagin



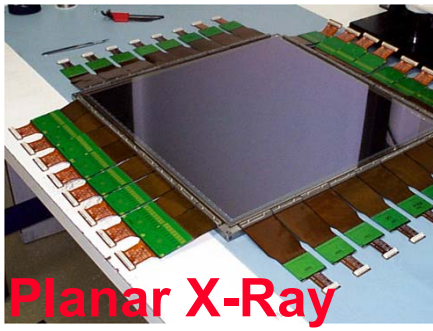




All Modalities Want:

- Larger Area Covered
- Smaller Pixels

⇒ Many Pixels (25 million)



Implications:

⇒ High Power Consumption & Density

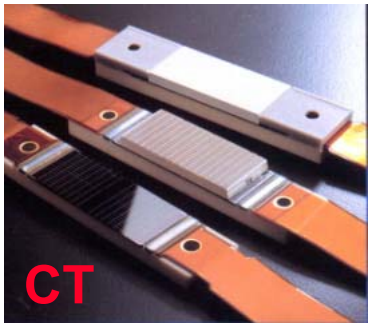
⇒ Large Number & Density of Connections

⇒ Modular Design

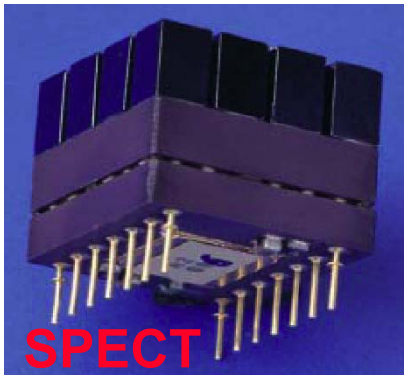
⇒ Dead Area Between Modules

⇒ Scintillator Arrays w/ Small Pixels

ckaging Improvements Would Help *All* Modaliti



Thanks To:



Tom Budinger, *LBNL*
Mike Casey, *CPS Innovations*
Simon Cherry, *UC Davis*
Neal Clinthorne, *Univ. of Michigan*
Jim Colsher, *GE Medical Systems*
Steve Derenzo, *LBNL*
Ruvin Deych, *Analogic*
Kathy Ferrara, *UC Davis*
Stuart Foster, *Univ. of Toronto*
Daniel Gagnon, *Picker Imaging*

Paul Granfors, *GE Medical Systems*
Grant Gullberg, *LBNL*
Anne Hall, *GE Medical Systems*
Floris Jansen, *GE Medical Systems*
Ron Keyser, *EG&G Ortec*
Jim LeBlanc, *GE Medical Systems*
Chuck Melcher, *CPS Innovations*
Kanai Shah, *RMD, Inc.*
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